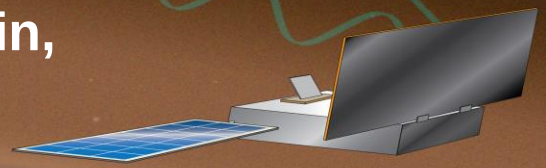
Low Cost Breakthroughs in Planetary Atmospheres and Interior Structures With Precision-Radio-Equipped Small Spacecraft

Sami Asmar, David Atkinson, David Bell, James Border, Ivan Grudinin, Joseph Lazio, Anthony Mannucci, Ryan Park, Robert Preston



Jet Propulsion Laboratory
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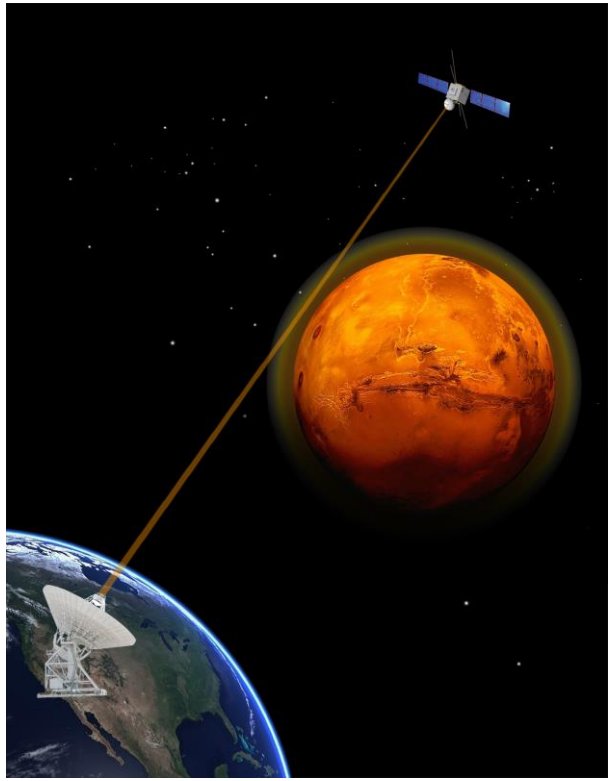
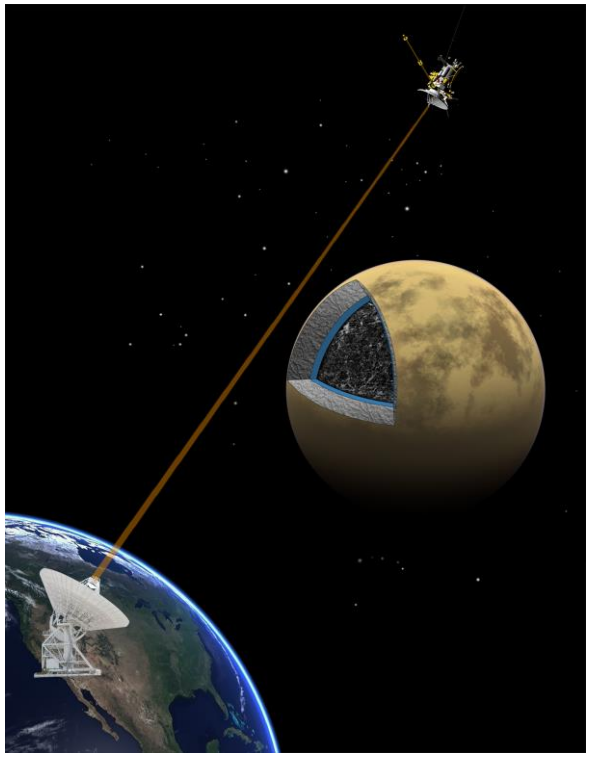
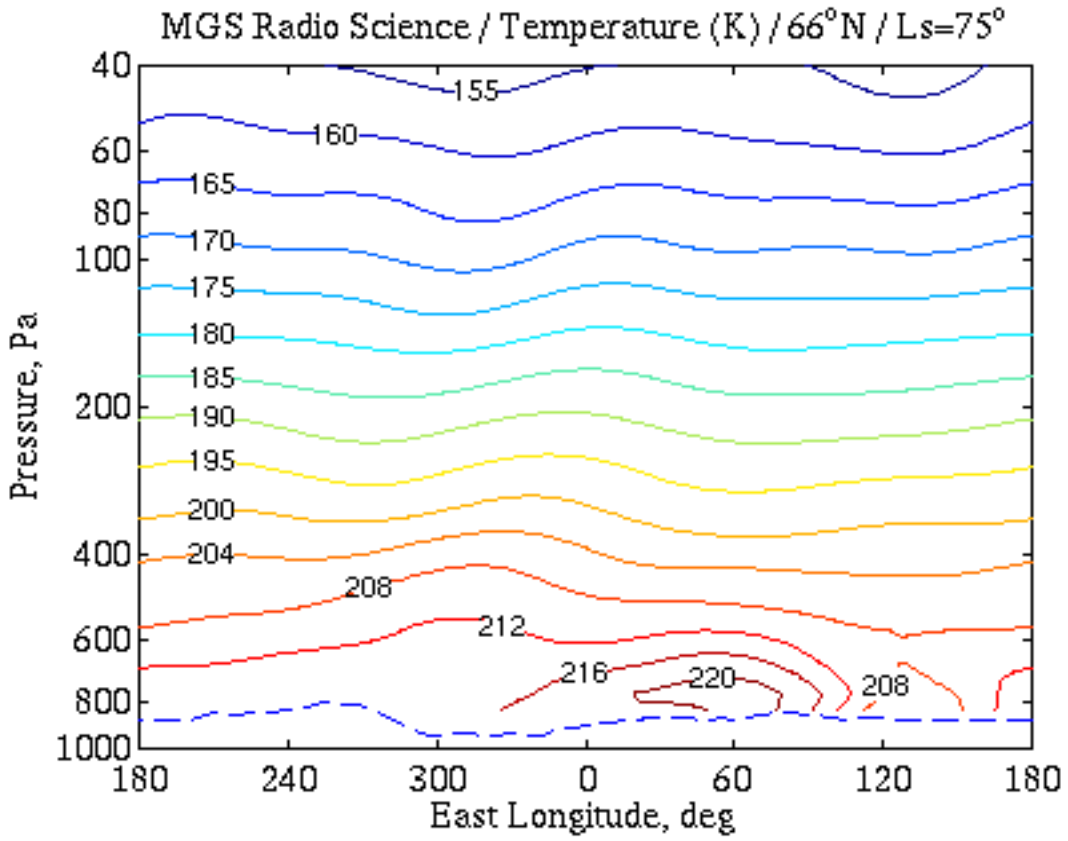
Quick Background on Radio Science

- It became apparent with early missions that occultations by planetary atmospheres would affect the quality of radio communications
- One person's noise is another's data
- Study the atmospheric properties
  - And other aspects of planetary science, solar science, and fundamental physics
- A recognized field of solar system exploration with instrument distributed between spacecraft & ground stations

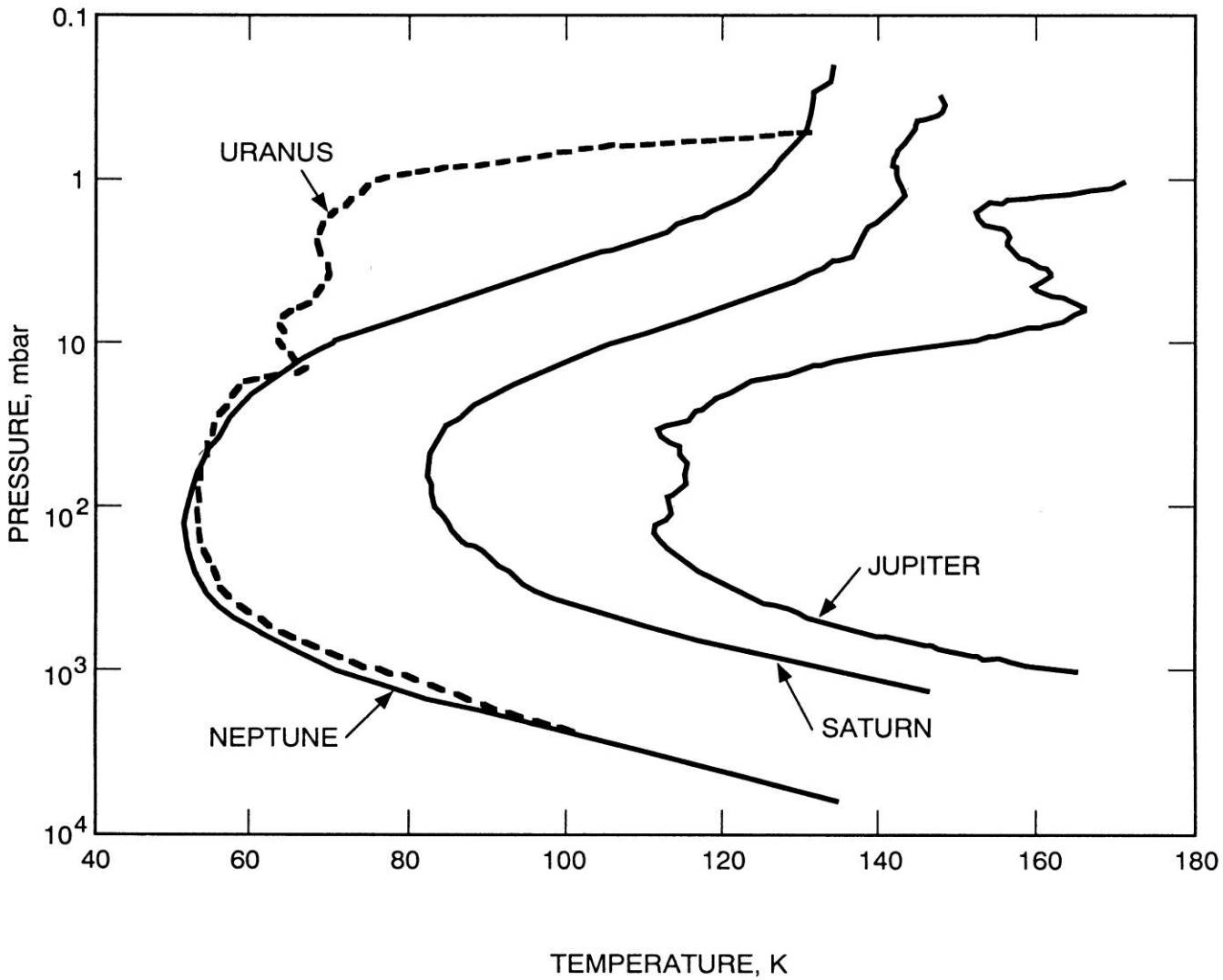




Atmosphere of Mars from MGS Occultations

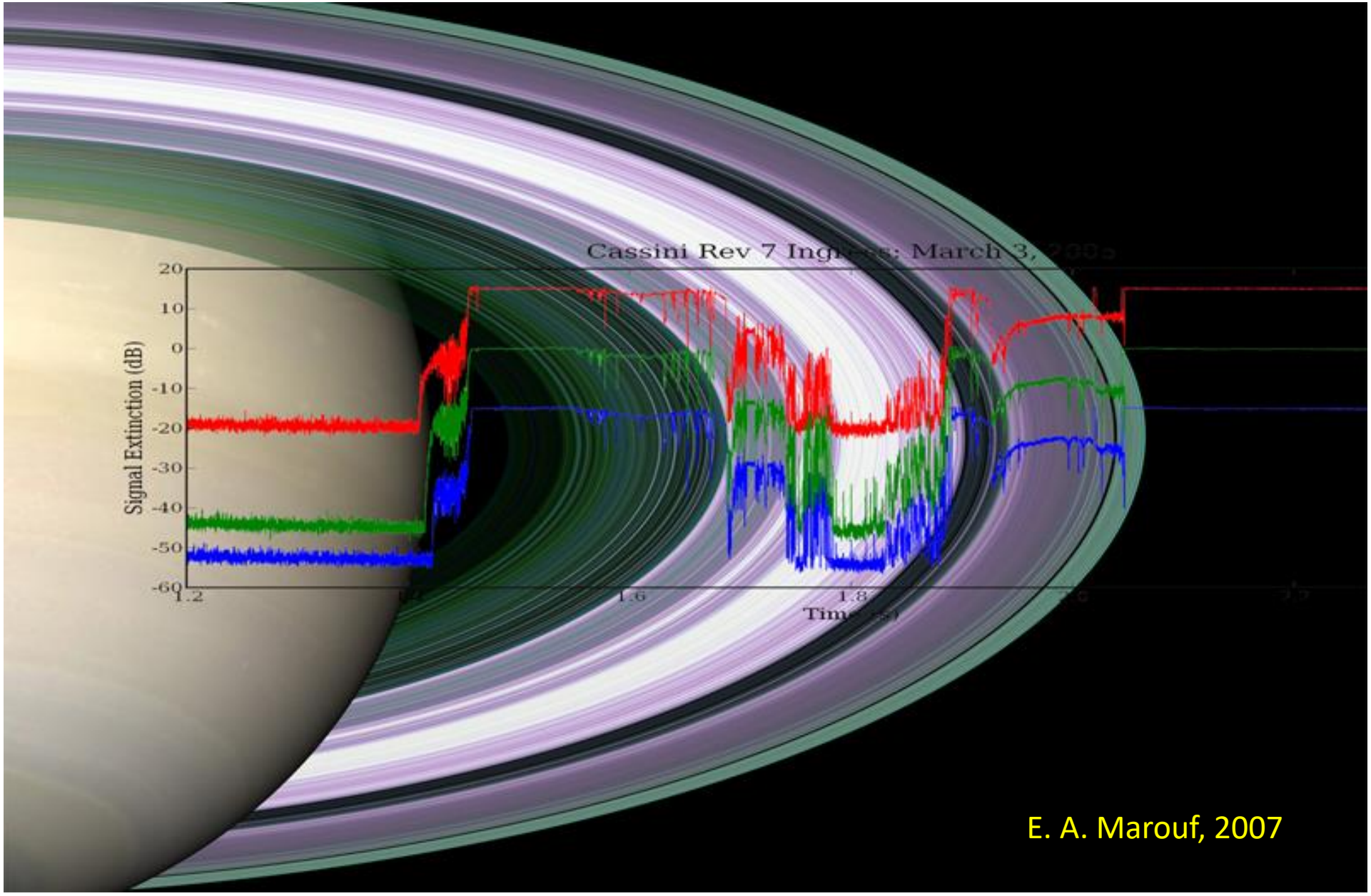


Atmospheres of Giant Planets

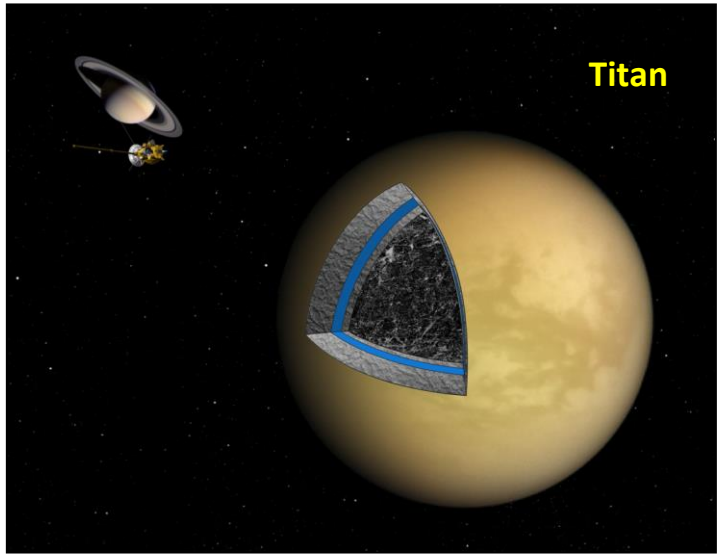


Temperature profiles for the giant planets derived from radio occultation data acquired with the Voyager spacecraft (from Lindal, 1992)

Saturn's Rings In the Cassini Era



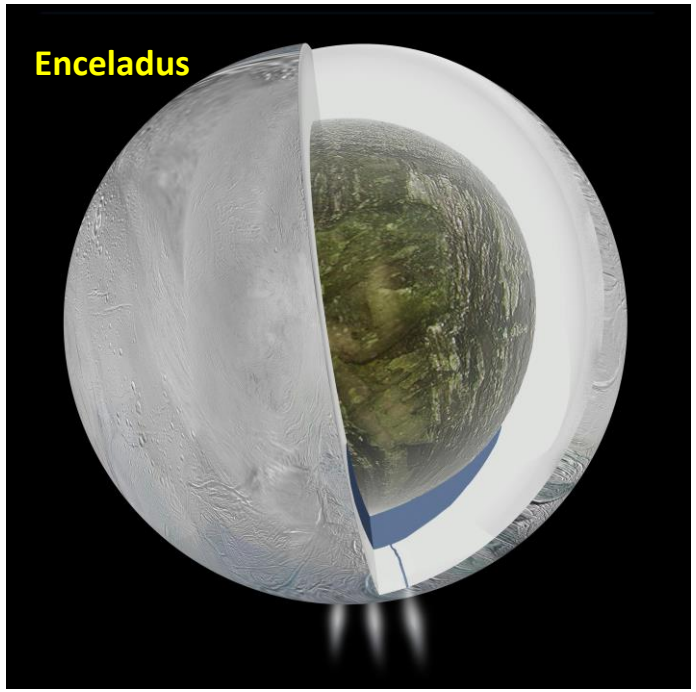
Icy Moons of Large Planets



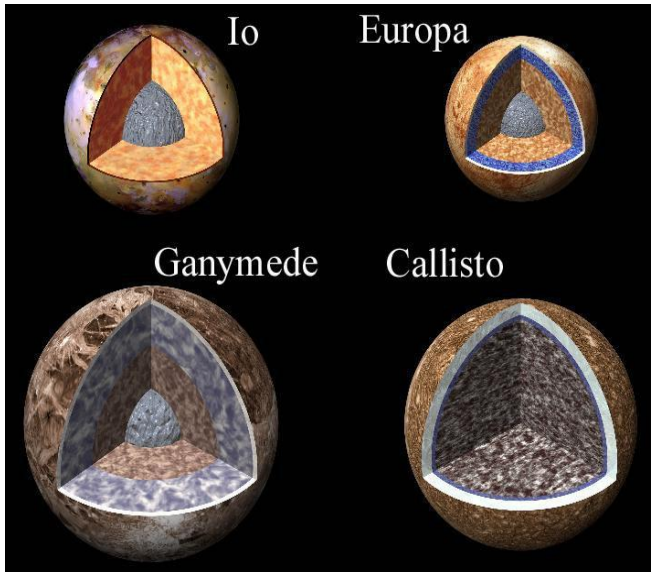
Tidal observations by Cassini gravity team

Titan: Iess et al., 2011 & 2012

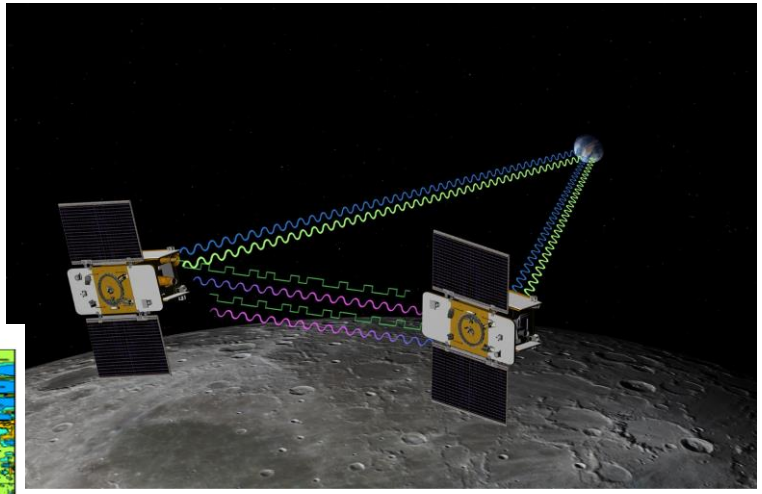
Enceladus: Iess et al., 2014

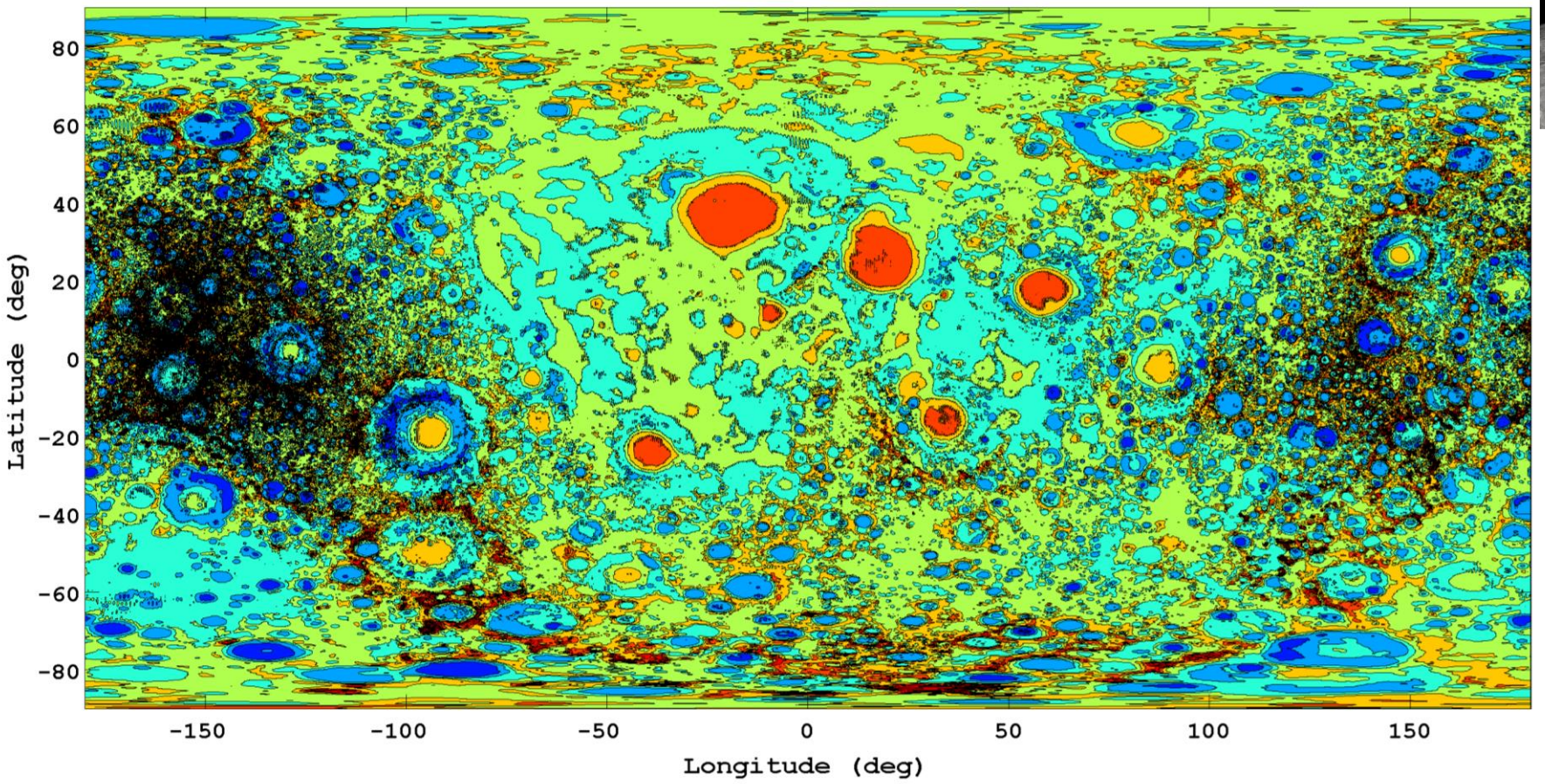


Models of the interiors of the Galilean satellites based on magnetic and gravity measurements



GRAIL Reveals Lunar Interior Structure

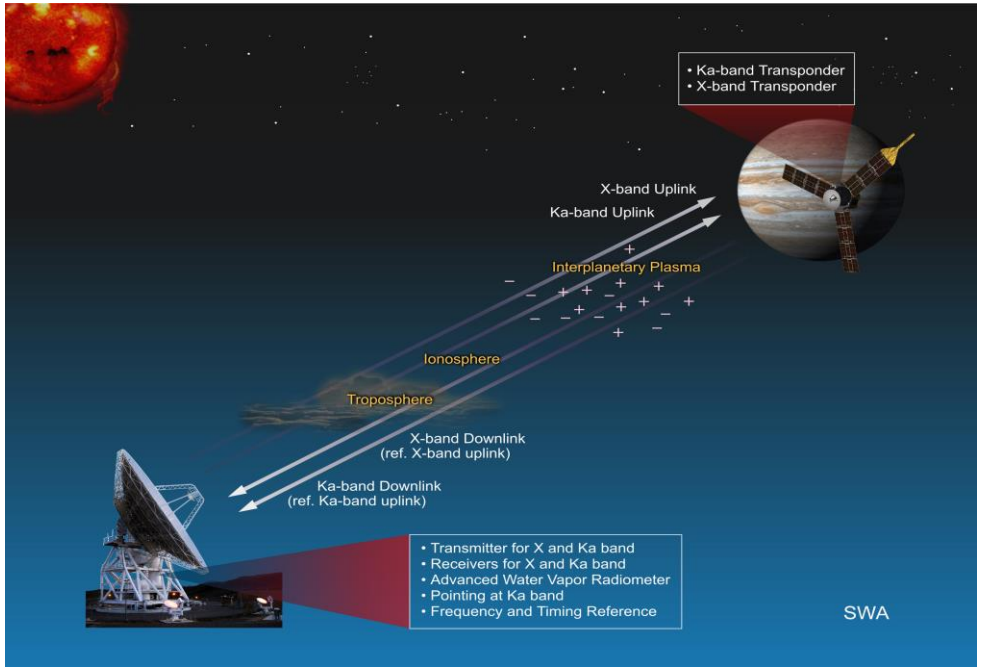




Recent Accomplishments

- Radio Science experiments utilizing spacecraft communications links have been conducted on almost every planetary mission in the past five decades
- Recent significant discoveries (fit NASA's themes for planetary exploration) include
  - Elucidation of lunar thermal history from GRAIL high precision gravitational field
  - Unveiling interiors of Titan, Enceladus, Mercury, Phobos, Vesta, Ceres, Mars, and cometary nuclei - providing key evidence for identifying subsurface oceans on icy moons
  - Sounding of Titan, Saturn, Mars, Venus, and Pluto's atmospheres
  - Profiling the structure of Saturn's rings
- Juno & Cassini currently measuring gravitational fields of Jupiter & Saturn to reveal interior structures
- InSight will soon characterize the Martian core
- Akatsuki will further study Venus' atmosphere
- Future experiments are planned at Mercury, Jupiter, and other environments

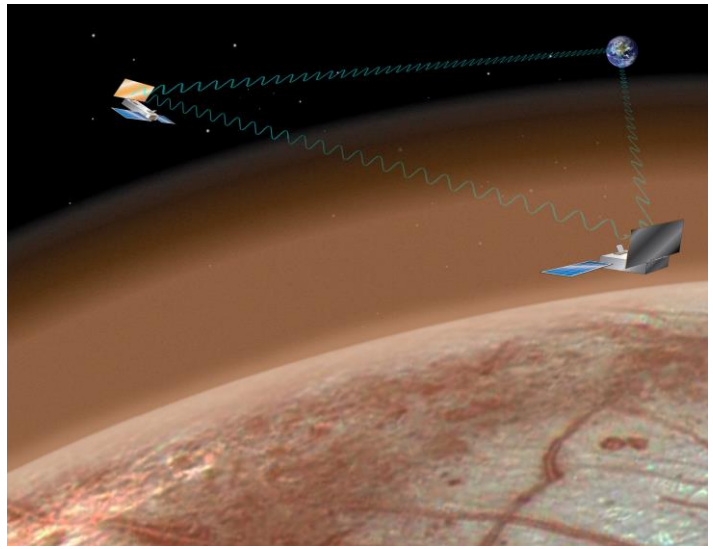
Cost



- Cost of Radio Science experiments varies among missions
- Depends on scientific objectives and the state of the telecommunications capabilities at the spacecraft and ground systems

1. Case 1: opportunistically use radio links without additional instrumentation
2. Case 2: augment the flight system with Ultra-Stable Oscillators to further advance their scientific capabilities especially for occultations of planetary atmospheres and rings
3. Case 3: add substantial instrumentation such as dedicated Ka-band transponders and augmented the ground system with specialized equipment for sophisticated calibration techniques

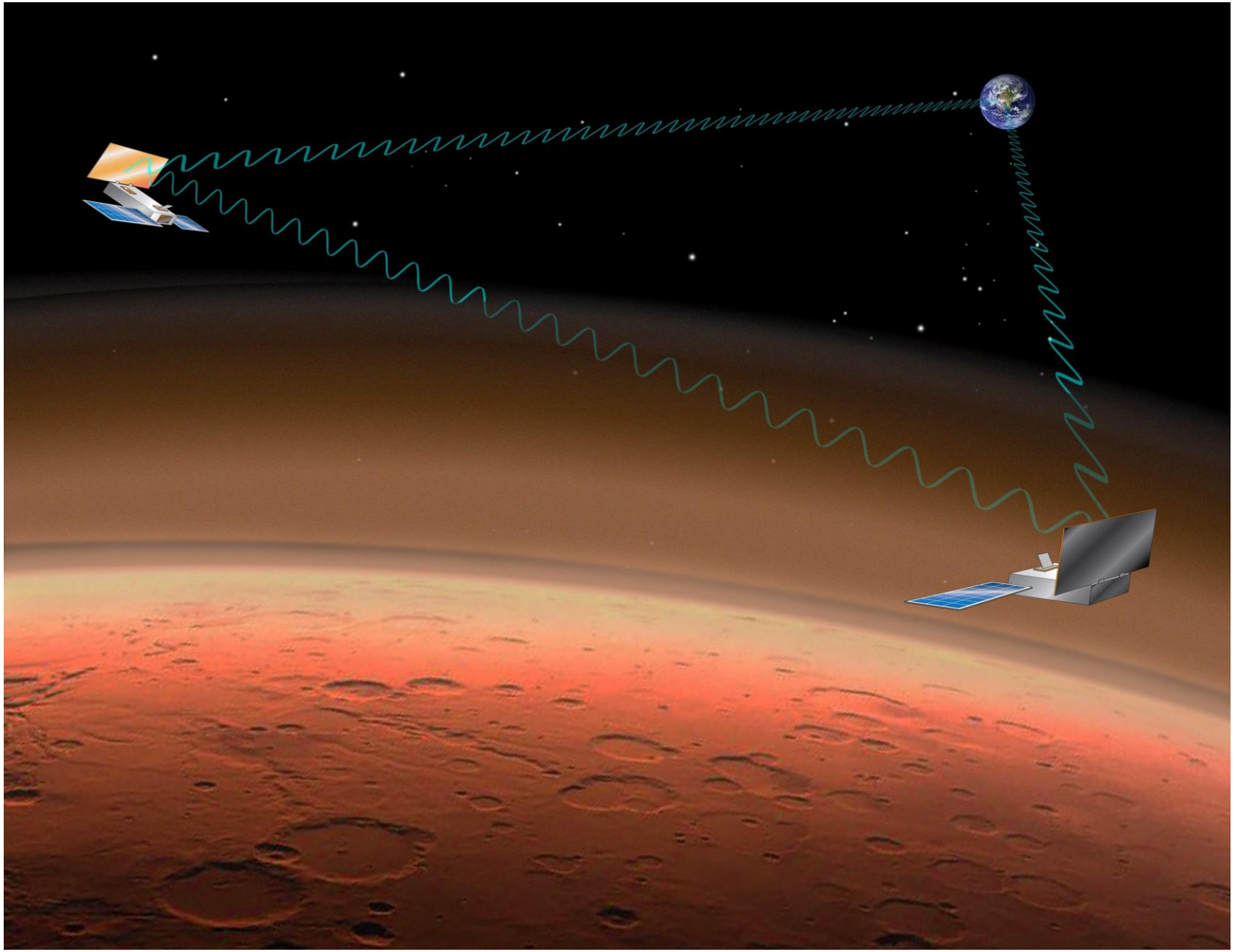
Future



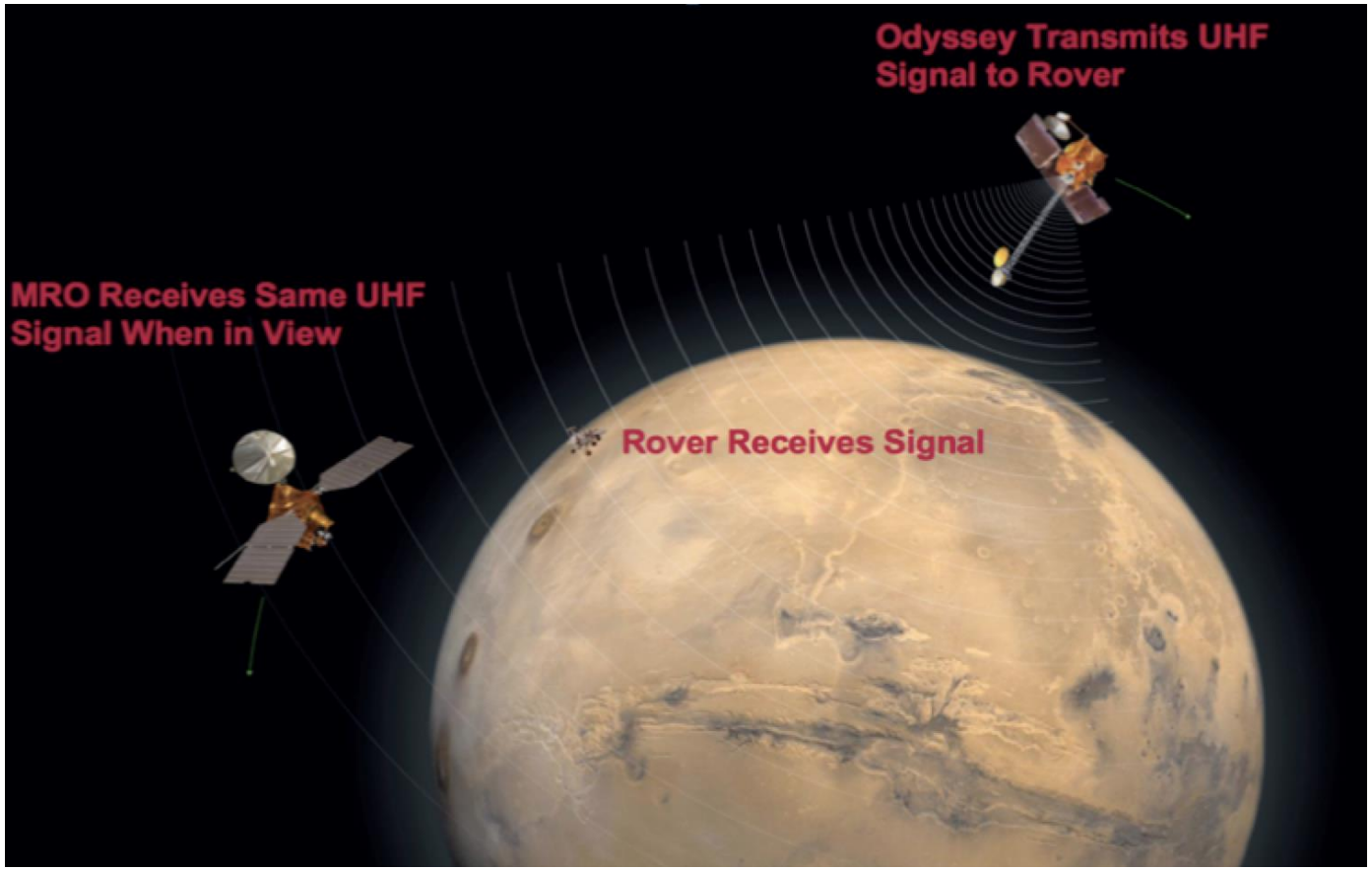
- Utilize technologies leading to additional scientific breakthroughs at lower cost
  - Part of infrastructure capabilities provided by space agencies and industry
- Selected science-enabling techniques include
  - Laser link science in the era of optical communications
  - Uplink radio occultation as a standard service with enabled transponders
  - Spacecraft-to-spacecraft link for rapid coverage and higher signal-to-noise ratio
  - Utilization of networks of small spacecraft including planetary CubeSats
- Selected science-enabling technologies include
  - Advanced precision ranging for Solar System dynamics and tests of General Relativity
  - Next generation ultra-stable oscillators for small spacecraft
  - Antenna mechanical noise reduction for precision Doppler gravity measurements
  - Science-based software-defined transponder

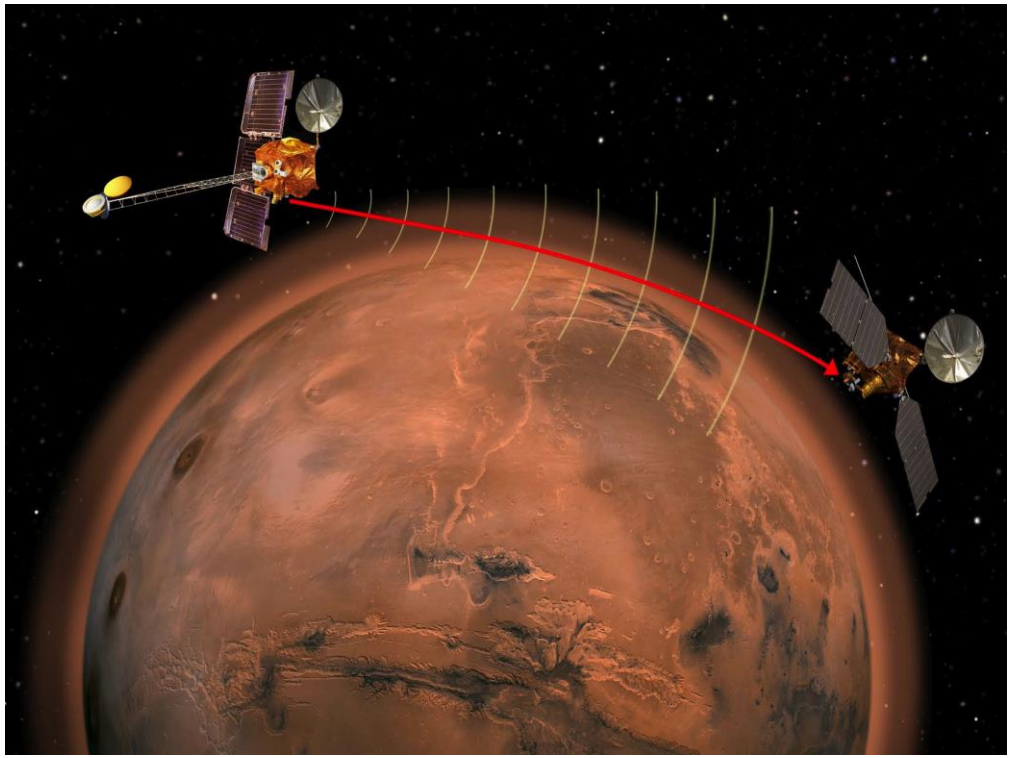
Concept:

MarCO-based CubeSats performing atmospheric radio occultation experiments at Mars

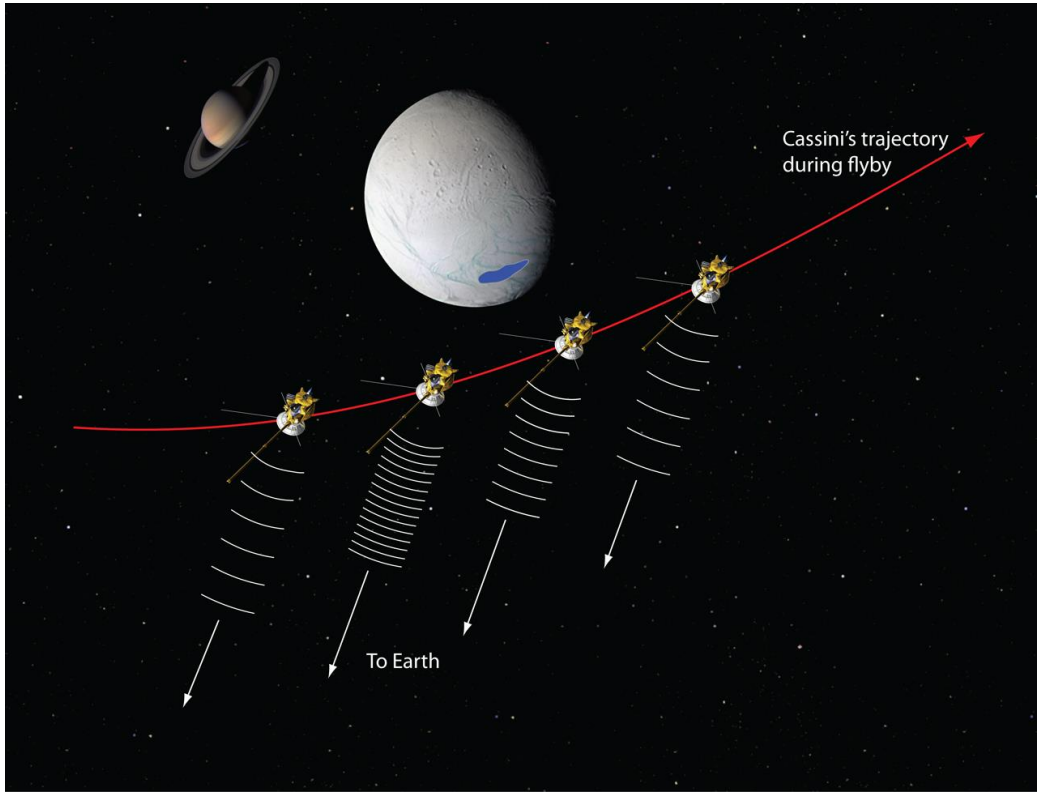


Demonstration proved advantages over traditional configuration





Technology



- Key to these advanced concepts are
  - science-quality radio links between multiple low cost small spacecraft or
  - mother-daughter spacecraft formation at planetary target configurations
- that enable the detailed investigations of the planetary gravitational fields and atmospheres
- These results, shedding a light at the interior and atmospheric structures, would otherwise not be possible at the same cost

Summary

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